1 Vacuum

1.1 Layout

Vacuum system layout will conform to the accelerator lattice layout. Accordingly, the vacuum system will consist of the following sections, as shown in Fig. 1.1.1.

- Injector and merger
- Main LINAC cryo-module
- Demerger and beam dump
- Spreaders and recombiners
- FFAG arcs and straight

The injector includes the electron gun and the injector cryo-module (ICM). This section is already exist from the Cornell Prototype ERL Injector project, and is to be relocated and re-used for the Cbeta project. The detail of this section is described in the Injection section of this report. The short merger beam line that connects the injector to the main LINAC is also described in the injector section.

The main LINAC cryo-module (MLC) is a self-containing accelerator section from vacuum system point of view, and is described in a separated section in this report. The interface between the MLC and the rest of the Cbeta vacuum system will be described in sub-section 4 below. The electron beams of 4 different energies (exiting and entering the MLC) will be split into four separated beampipes and then recombined into a single beampipe for optics and timing reasons. The most important feature of this section is to provide beam path length adjustments for each of four energy electron beams.

The FFAG arcs and long straight sections consist of more or less repetitive structures of magnets. Thus units of repetitive simple beampipes will be designed for the FFAG sections. The energy recovered electron beam (with lowest energy) is demerged into a high power beam dump. The beam dump transport beamline is also exist from the Cornell Prototype ERL Injector project, and is to be relocated and re-used for the Cbeta project.

1.2 Requirements and Design

Vacuum beampipes are part of beam transport system. A list of vacuum requirements and design considerations is given below.

- Produce adequate level of vacuum, through proper beampipe material selection and preparation, and vacuum pumping. The required level of vacuum will be determined by acceptable beam losses due to residual gas scattering, among other factors.

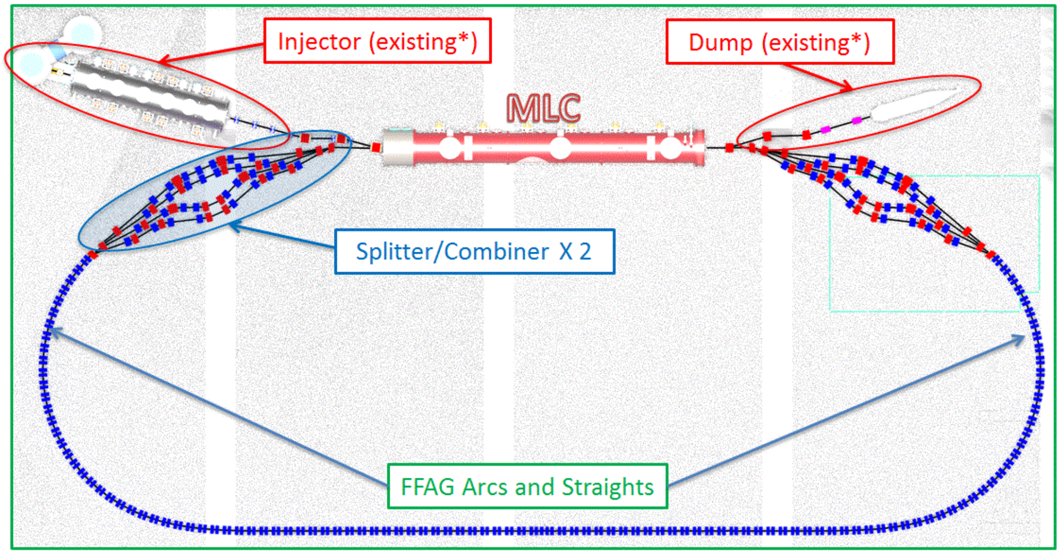

Figure 1.1.1

- Aluminum (6061-T6 or T4) is preferred material for the beampipes for its good electric conductivity (resistive-wall), no residual radioactivity (from beam losses) and low magnetization (from cold work and welding etc.)

- Provide sufficient large beam apertures, while allowing magnets position adjustment.

- With high beam current and closely spaced electron bunches, design efforts will be made to keep low beam impedance, including smooth beampipe inner profiles, RF shielded bellows and gate valves, gentle transitions between different beampipe cross sections, etc.

- Beampipes will host various beam instrumentation and diagnostics, such as BPMs and instrumentation ports (for beam viewers, etc.)

1.3 Construction, Installation and Operation

1.3.1 FFAG Arcs and Straight Sections

In the FFAG arcs and straight, permanent magnets are arranged in more or less periodic double-magnet cells. The relatively short drifts between magnets are reserved as much as possible for vacuum pumping, beam instrumentation. Therefore, it is efficient use of these drifts by constructing beampipe assembly through multiple FFAG magnet cells, reducing number of beampipe flanges. A typical 4-cell beampipe assembly is depicted in Fig. 1.3.1. The FFAG beampipes may be made of extruded 6061-T6 (or T4) aluminum with cross section designed to meet both required beam apertures and magnet clearances.

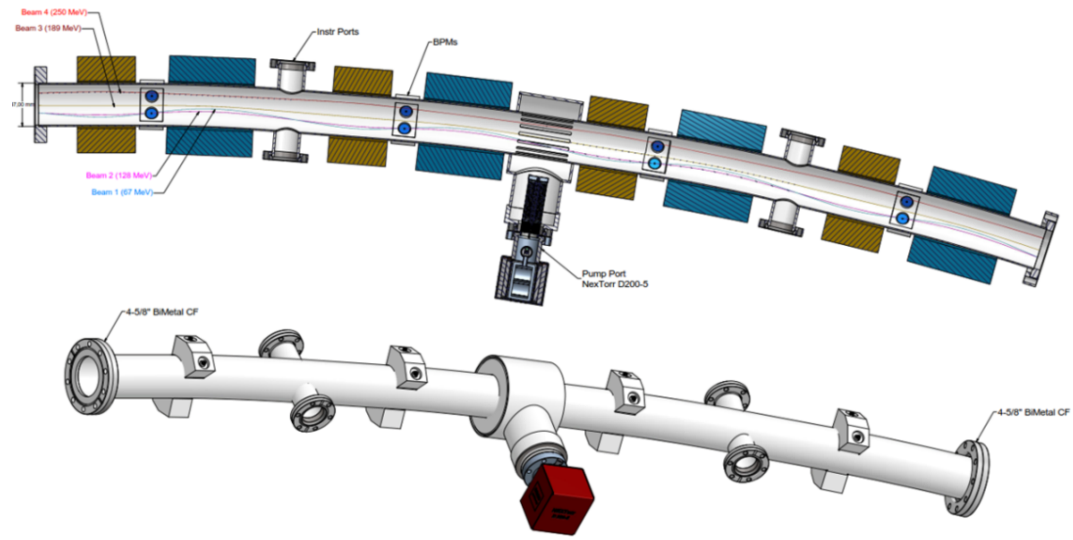

Figure 1.3.1: A suggest FFAG arc 4-cell beampipe design. The 1.6 m long beampipe assembly houses 4 sets of BPMs, two beam instrumentation ports and one pump port.

1.3.2 Spreaders and Recombiners

To keep low beam impedance, the beam splitting and combining vacuum chambers may be made of aluminum (6061-T6) with smooth beam path transitions, as illustrated by an example vacuum chamber used for the Cornell Prototype Injector project, in Fig. 1.3.2. The separated beampipes will be designed to allow independent beam path length adjustment by using sets of 4 RF-shielded bellows. Beam collimators (or/and scrappers) may also installed in these single beam chambers, together with BPMs and other beam instruments.

1.3.3 Ion Clearing

Ion trapping may not be avoidable without active clearing method, due to the nature of in the final CBETA CW beam operations. Low impedance clearing electrodes may be deployed at various locations to reduce ill-effect from the ion trapping. Thin electrodes directly deposited onto the interior walls of beampipes have been successfully deployed in CesrTA and Super KEKB. A clearing electrode beampipe of this style was made and tested in the Cornell prototype ERL injector (see Fig. 1.3.3).

1.3.4 Construction and Installation

All vacuum beampipes will be fabricated following stringent UHV procedure and practice. All beampipe assemblies will be certified to be leak-free, and will be baked in vacuum up to 150 C. Most of the beampipes will be delivered to BNL to be assembled to the girder units. The baked beampipes will be back-filled with chemically filtered nitrogen (with moisture and THC at ppb level) for transportation and girder assembling. The same nitrogen system must be used to purge the beampipes whenever any flange is to be opened for connection, etc.

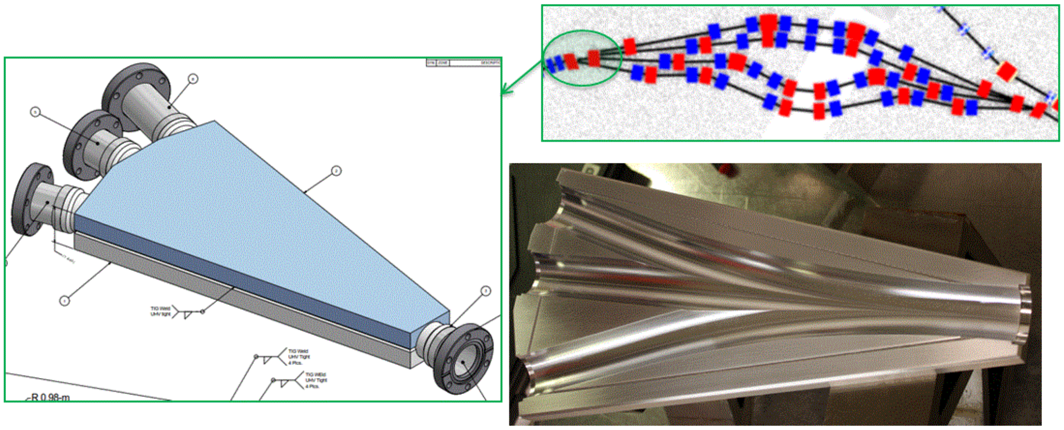

Figure 1.3.2: Example design for beam splitting and combing chamber, by welding two machined aluminum halves with smooth beam path transitions.

Operational experiences of Cornell prototype ERL injector, as well as CESR vacuum systems have demonstrated that in situ bakeout is not necessary with above beampipe preparation and installation procedures.

The injector, the ICM and the beam dump are to be installed and surveyed into locations. These sections are equipped with RF-shielded gate valves. The splitter/combiner and the FFAG sections will be installed in corresponding girder units. The detail installation sequence will be developed during the engineering design process to minimize air exposure of the vacuum beampipes. Further system and cost optimization will be carried out to decide if any additional RF-shielded gate valves are needed in these sections.

1.3.5 Pumping

With very limited spaces between magnets, compact and high capacity non-evaporable getter (NEG) pumps will be used, such as CapaciTorr (sintered NEG modular pump) and NexTorr (combination NEG and ion pump), see Fig. 1.3.4 for example pumps. The locations of pumps will optimized during CBETA engineering designs, with aid of vacuum simulations (see Section 4).

1.3.6 Instrumentation

Ionization vacuum gauges and ion pumps will be used as primary vacuum signals. Residual gas analyzers (RGAs) will also installed in strategic location for vacuum system diagnostics and in-situ trouble-shooting. Vacuum system inter-lock based on combinations of ion gauges, ion pumps and low vacuum gauges (such as Pirani gauges) will be implemented to protect critical accelerator components, such as the DC photo-cathode electron gun, ICM and MLC, etc.

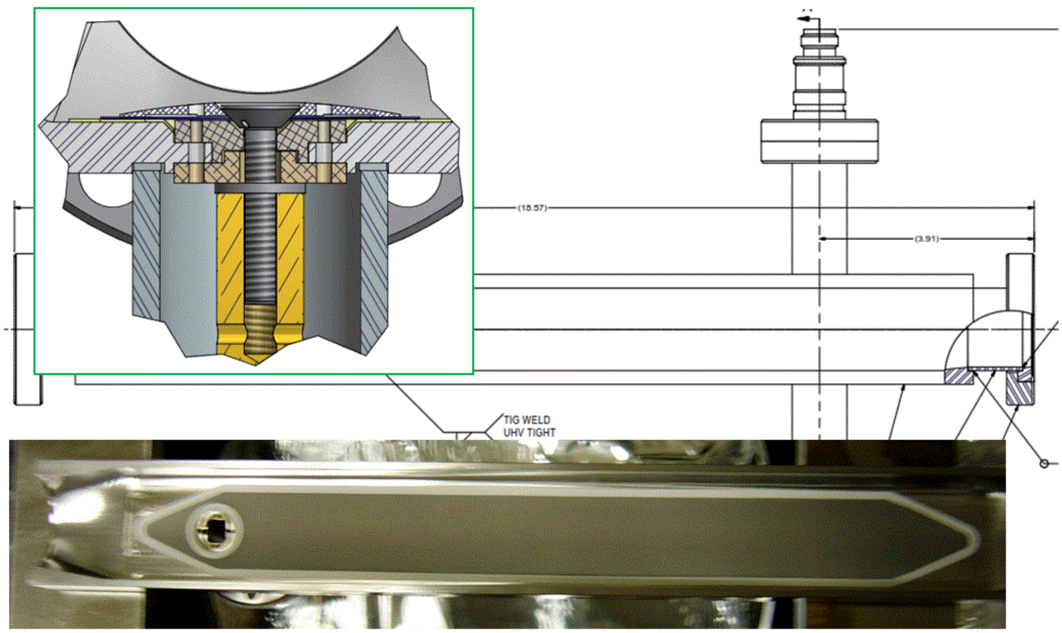

Figure 1.3.3: Low impedance ion clearing electrode chamber tested in the Cornell prototype ERL injector. The electrodes are made of a tungsten thin film (0.1 mm in thickness) on top of a thin (0.2 mm) alumina substrate. Both alumina and tungsten thin films are deposited via thermal-spray technique. A low profile electric connection is shown in the insert.

1.4 Vacuum Pumping Simulations

With highest beam energy of 200 MeV, synchrotron radiation induced gas desorption from the beampipe wall is negligible. Therefore thermal outgassing is the only source of gas in the beampipes. With pre-installation bakeout of all beampipes, and venting/purging with chemically filtered nitrogen, low thermal outgassing rate ($< 1^{-9}$ torr-l/s-cm^{2}2) can be achieved within 24 hour of pumpdown, and continuing decrease with time as $q = q_i t^{-\alpha}$, with $\alpha \sim 1$.

Vacuum system performance design will be aided by 3D vacuum simulations, using a 3D tracking program, MolFlow+ (http://test-molflow.web.cern.ch/). As examples, Fig. **??** compares simulated pressure profiles with two different pumping configurations in a 4-cell FFAG beampipe, and the results showed one pump per 4-cell beampipe is sufficient. Fig. 1.4.2 demonstrates the continuing improvement over time for a 4-cell FFAG beampipe with one pump per cell. Vacuum simulations will be carried out for all the CBETA sections as more engineering details of the beampipes becoming available.

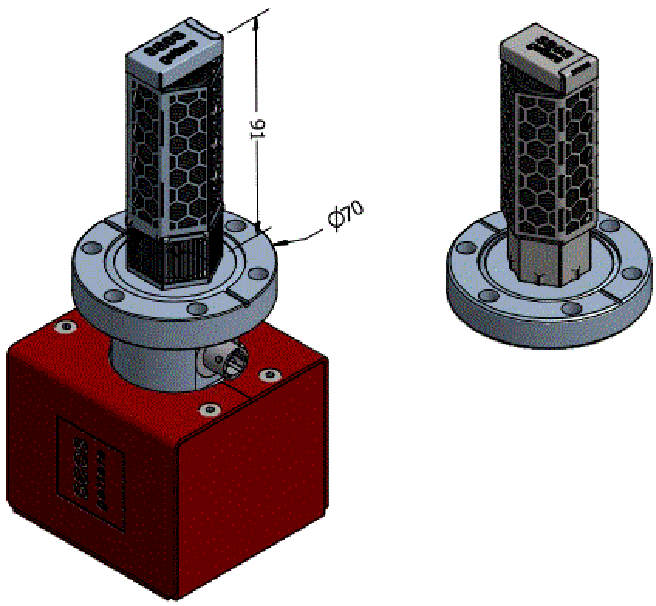

Figure 1.3.4: Typical vacuum pumps for CBETA vacuum system, with a 200-l/s NexTorr (left) and a 200-l/s CapaciTorr (right)

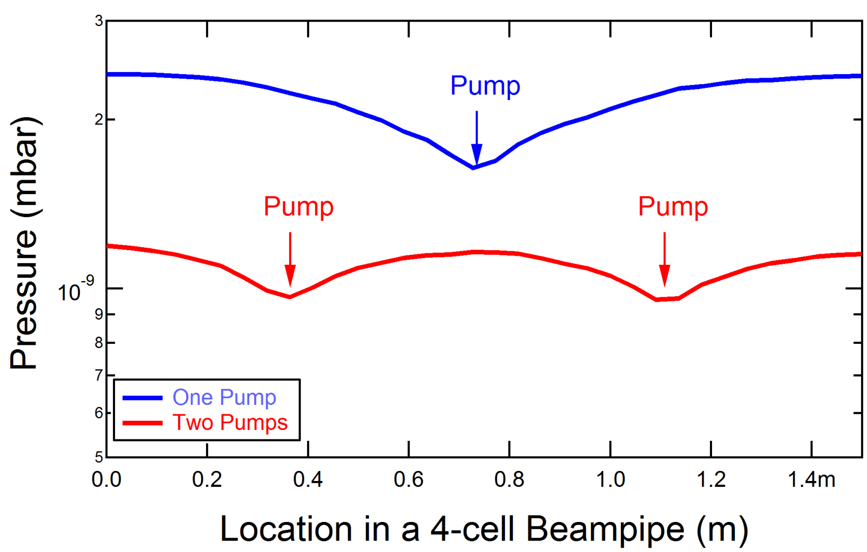

Figure 1.4.1

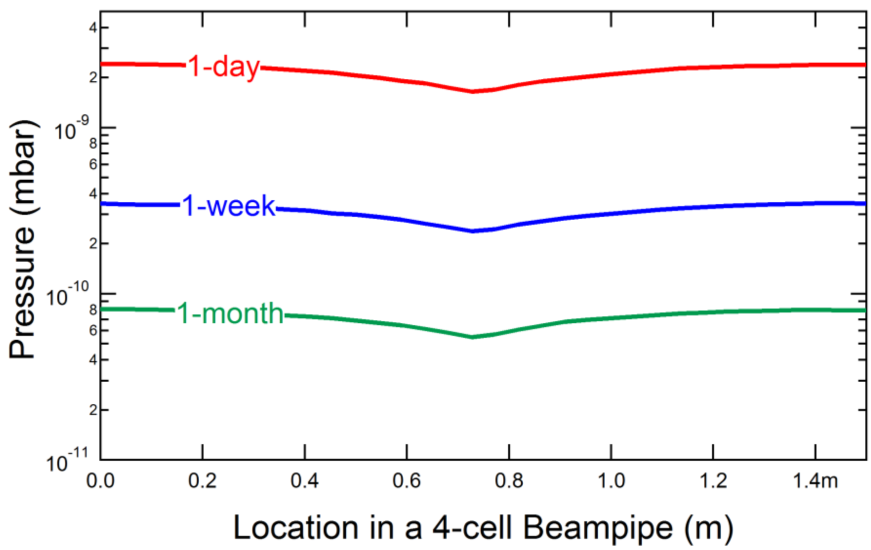
1-day
1-week
1-month
Pressure (mbar)
4
2
10^{-9}
8
6
4
2
10^{-10}
8
6
4
2
10^{-11}
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4m
Location in a 4-cell Beampipe (m)

Figure 1.4.2